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APPLICATION FOR UNITED STATES LETTERS PATENT

SPECIFICATION

TO ALL WHOM IT MAY CONCERN:

Be it known that Stephen B. Memory
a citizen of the UNITED KINGDOM, residing at 1402 40th Avenue, Kenosha
in the County of Kenosha and State of Wisconsin
and Jianmin Yin
a citizen of CHINA, residing at 2504 - 18th Street #24, Kenosha
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and Samuel J. Collier
a citizen of the UNITED STATES, residing at 1670 Pope Road, Danville
in the County of Boyle and State of Kentucky
have invented a new and useful

REFRIGERATION SYSTEM

of which the following is a specification.

REFRIGERATION SYSTEM

FIELD OF THE INVENTION

This invention relates to refrigeration systems, and more particularly, to refrigeration systems that include components operating on the vapor compression cycle for cooling a refrigerant and which are provided with suction line heat exchangers.

BACKGROUND OF THE INVENTION

Refrigeration systems such as heat pump systems used for heating and cooling, air conditioning systems used for cooling air, refrigerators and freezers and the like most in use today operate on the so-called vapor compression principle. In these systems, a refrigerant is compressed by a compressor and then passed to a gas cooler (including condensers) to cool and/or condense the compressed refrigerant while at high pressure. The high pressure refrigerant is then passed to an expansion device such as a capillary or an expansion valve and then to an evaporator at a lower pressure where the refrigerant absorbs the latent heat vaporization of the refrigerant and/or sensible heat.

The refrigerant then exits the evaporator and is returned to the inlet of the compressor at low pressure to be compressed so that the cycle can be repeated continuously.

Most such systems include an accumulator somewhere in the path between the evaporator and the compressor which principally serves to contain excess refrigerant to assure that the system is always charged

with sufficient refrigerant to operate. Many such systems, particularly those operating on a transcritical refrigerant such as CO₂ also include a so-called suction line heat exchanger. Such suction line heat exchangers (also sometimes referred to as internal heat exchangers) may also be found in
5 very large systems employing more or less conventional refrigerants and in systems of more modest size operating with the refrigerant commonly known as R134a.

A suction line heat exchanger includes two fluid flow paths in heat transfer relation with one another. One of the flow paths typically
10 interconnects the gas cooler of the system with the evaporator at a location upstream of the expansion device and downstream of the gas cooler. The other flow path is located in the path of refrigerant flow between the evaporator and the inlet of the compressor.

In systems using more or less conventional refrigerants, the
15 presence or absence of a suction line heat exchanger depends upon whether the added efficiency produced by the presence of the suction line heat exchanger is sufficient to offset the cost of the suction line heat exchanger itself and whether the system, when installed in its operating environment, can tolerate the bulk, both in terms of volume and in weight, of an additional heat exchanger. A system typical of the latter situation is one that
20 may be employed in a vehicular application such as an automotive air conditioner.

On the other hand, when operating with transcritical refrigerants such as CO₂, suction line heat exchangers are considered almost a
25 virtual necessity in spite of their cost, weight or bulk because of the consid-

erable improvement in efficiency that is obtained with them with such refrigerants.

Given modern day concerns for energy and the cost thereof, it is highly desirable that such a refrigeration system be as efficient as possible so as to minimize the expense of energy. The present invention is directed to improving the efficiency of a vapor compression refrigeration system including a suction line heat exchanger by obtaining even higher levels of efficiency than those obtainable with today's technology.

SUMMARY OF THE INVENTION

It is the principal object of the invention to provide a new and improved refrigeration system of the vapor compression type that employs a suction line heat exchanger by increasing the efficiency thereof. It is also a principal object of the invention to provide a new and improved method of operating a vapor compression refrigeration system of the type employing a suction line heat exchanger.

According to one object of the invention, there is provided a refrigeration system that includes a compressor having an inlet and an outlet, a gas cooler connected to the compressor outlet to cool compressed refrigerant received from the compressor and an evaporator connected to the gas cooler for receiving cooled, compressed refrigerant therefrom. The system includes a suction line heat exchanger which has a first refrigerant flow path interconnecting the gas cooler and the evaporator and a second refrigerant flow path in heat exchange relation with the first refrigerant flow path and interconnecting the evaporator and the inlet of the compressor.

5 The system including the evaporator is constructed to deliver refrigerant from the evaporator to the second refrigerant flow path in the suction line heat exchanger at a quality less than 1 and to deliver refrigerant from the second flow path of the suction line heat exchanger to the inlet of the compressor at a quality substantially equal to 1 or in a super heated condition.

10 In one embodiment of the invention, an accumulator is located in the system and is located downstream of the second flow path and upstream of the inlet of the compressor.

15 In another embodiment of the invention, the system is provided with a compressor, a gas cooler and an evaporator as before. An accumulator is connected to the evaporator to receive refrigerant therefrom and a suction line heat exchanger is located in the system and has a first refrigerant flow path interconnecting the gas cooler and the evaporator and a second refrigerant flow path in heat exchange relation with the first refrigerant flow path and interconnecting the accumulator and the compressor inlet and receiving refrigerant from the accumulator at a quality less than 1 and delivering the refrigerant to the compressor inlet at a quality substantially equal to 1 or in a super heated condition.

20 According to the foregoing embodiment of the invention, the accumulator is a housing having an intended level of liquid refrigerant and a refrigerant vapor space above the intended level of liquid refrigerant. A first outlet from the accumulator is disposed above the intended level of liquid refrigerant and a second outlet from the accumulator is located below

the intended level of liquid refrigerant. The first and second outlets are in fluid communication with each other and with the compressor inlet.

In a preferred embodiment, an accumulator such as mentioned before is constructed so that liquid refrigerant within the accumulator is entrained or educed into the refrigerant vapor.

One embodiment of the invention contemplates that the second outlet of the accumulator is disposed in a wall of the housing separate from the first outlet.

Preferably, the accumulator includes a tube within the housing and both the outlets comprise respective inlet ports in the tube.

In one embodiment, the inlet port defining the first outlet is upstream of the inlet port defining the second outlet to provide entrainment and/or eduction of the liquid refrigerant.

A highly preferred embodiment contemplates that the tube be a "U" or "J"-shaped tube having a first leg having the first inlet therein at a location above the intended level of liquid refrigerant and a second leg connected to the first leg by a bight and having the second outlet below the intended level of liquid refrigerant.

In such an embodiment, the accumulator may also include an intended level of system lubricant below the intended level of refrigerant liquid and the bight is located below the intended level of system lubricant and includes a system lubricant inlet port therein. According to this embodiment, lubricating oil from the system is also educed from the accumulator by the flow of refrigerant vapor therefrom.

According to another facet of the invention, there is provided a method of increasing the efficiency of a system including a vapor compression cooling cycle and having an evaporator with an inlet connected to an outlet of a gas cooler whose outlet in turn is connected to the inlet of a compressor. The compressor has an outlet connected to the inlet of the gas cooler and a suction line heat exchanger having two fluid flow paths in heat exchange relation with one another is provided. One of the flow paths is located between the evaporator inlet and the compressor outlet and the other flow path is located between the evaporator outlet and the compressor inlet. Refrigerant is located in the system and is of the type that may exist as a vapor, a liquid or a mixture of vapor and liquid whose quality at a given point is defined as the weight ratio of the mass of refrigerant vapor to the combined mass of refrigerant vapor and liquid refrigerant at the given point. The method includes the steps of (a) introducing refrigerant into the other flow path of the suction line heat exchanger at a quality less than 1; and (b) introducing refrigerant that has passed through the second flow path into the compressor inlet at a quality that is substantially equal to 1 or in a super heated condition.

According to the invention, a method of operating a refrigeration system having a vapor compression cooling cycle and of the type generally described previously includes the steps of (a) introducing refrigerant from an evaporator outlet into an accumulator; (b) discharging refrigerant having a quality less than 1 from the accumulator into the other flow path of the suction line heat exchanger; and (c) introducing refrigerant

having a quality substantially equal to 1 or super heated vapor from the other flow path into the compressor inlet.

In one embodiment of the invention, the step of discharging refrigerant having a quality less than 1 from the accumulator into the other flow path of the suction line heat exchanger is performed by entraining or 5 educating liquid refrigerant from the accumulator by refrigerant vapor exiting the accumulator to the compressor inlet.

In one embodiment, the latter step is performed within the 10 accumulator while in another embodiment, the latter step is performed downstream of the accumulator.

Other objects and advantages will become apparent from the following specification taken in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

15 Fig. 1 is a schematic of one form of vapor compression system made according to the invention;

Fig. 2 is a schematic of a modified embodiment of the refrigeration system;

20 Fig. 3 is a somewhat schematic, sectional view of one type of accumulator and educating system that may be employed in the invention; and

Fig. 4 is a somewhat schematic cross-sectional view of another form of accumulator and eduction system.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Preferred embodiments of a refrigeration system made according to the invention and methods of operating the same will be described herein principally in the environment of so-called vehicular air conditioning systems. However, it is to be understood that the principles of the invention may be employed with efficacy in cooling cycles utilized in heat pumps, and in refrigeration systems generally, including refrigerators, freezers and other cooling devices as, for example, cooling systems for electronic components. Further, the invention is also useful in non-vehicular applications as well. Consequently, no limitation as to any particular type of refrigeration system or particular environment of use is intended except insofar as specifically stated in the appended claims.

Reference herein will be made to certain terms as, for example, the "quality of the refrigerant". Quality is as conventionally defined, namely, the weight ratio of the mass of refrigerant in the vapor phase to the total mass of refrigerant, i.e., the combined mass of liquid refrigerant and refrigerant vapor, at a given point in the system. Thus, refrigerant wholly in the vapor phase will have a quality of 1 while refrigerant wholly in the liquid phase will have a quality of zero. Refrigerant that is both in the liquid and vaporous phase will have a quality greater than zero and less than 1, the exact number being determined by the ratio of refrigerant vapor to total refrigerant.

A quality "substantially equal to 1" is a refrigerant having a quality of 1 or possibly slightly less. The quality will be such that liquid refrigerant present, if any, will be insufficient to cause damage to the sys-

tem compressor. The deviation from a quality of 1 that is tolerable will depend on both the compressor and refrigerant used in the system.

A quality of "less than 1" means a refrigerant that contains sufficient liquid refrigerant that, if passed to the system compressor, could damage the compressor.

5 The term "gas cooler" is intended to include condensers.

The terms "eduction" and "entrainment" are used interchangeably.

10 With the foregoing in mind, embodiments of the invention will be described. With reference to Fig. 1, the same is seen to include a compressor 10 for a refrigerant. The compressor 10 includes an outlet 12 and inlet 14. The outlet 12 is connected to an air/gas or liquid heat exchanger in the form of a gas cooler 16. Compressed refrigerant from the compressor flows in a line 18 to the gas cooler where it is cooled and/or condensed, typically by air, flowed through the gas cooler 16 by means of a fan 20 or the like. However, cooling for the refrigerant can be accomplished by other means as, for example, by using a liquid coolant.

15 From the gas cooler, the compressed refrigerant at high pressure passes in a line 22 to a first flow path 24 within a suction line heat exchanger 26. The suction line heat exchanger also includes a second flow path 28 which is in heat exchange relation with the first flow path 24.

20 From the first flow path 24, the refrigerant is connected by a suitable conduit 30 to an expansion device 32 which may be in the form of an expansion valve, a capillary tube, or any other type of expansion device usable in refrigeration systems. The expansion device 32 reduces the

pressure of a refrigerant which is then passed along a conduit 34 to the inlet 36 of an evaporator 38. As shown, the evaporator 38 is an air/liquid heat exchanger and the liquid refrigerant, now at low pressure, is evaporated by means of an air stream passed through the evaporator 38 by a fan 40. Within the evaporator 38, the latent heat of evaporation as well as sensible heat is rejected to the air stream generated by the fan 40. Of course, the latent heat and sensible heat of the refrigerant could be rejected to a liquid coolant, if desired.

Evaporated refrigerant emerges from the evaporator 38 at an outlet 40 and is conducted by a conduit 42 to the second flow path 28 of the suction line heat exchanger 26. According to the invention, refrigerant emerging from the evaporator 38 at the outlet 40 and entering the second flow path 28 is at a quality less than one. Qualities as high as 0.9 - 0.95 provide increased efficiency of the system as will be described. However, increases in efficiency are increased for even lower qualities. The main point is that the quality be less than one as previously defined and have a lower limit that is sufficiently high that the desired heat rejection from the air to the refrigerant within the evaporator 38 occurs.

From the second flow path 28 of the suction line heat exchanger 26, the refrigerant is now passed at a relatively high quality, not necessarily, but preferably, substantially equal to one as previously defined, by a conduit 44 to a conventional accumulator 46 which in turn discharges through a conduit 48 to the inlet 14 of the compressor 10. Refrigerant leaving the accumulator 46 is at a quality that is substantially equal to one as previously defined. It is desirable, though not absolutely necessary, that

the refrigerant entering the compressor inlet 14 be substantially at or slightly above its saturation temperature as opposed to a super heated temperature to reduce the heat loading on the compressor 10. However, in some cases super heated vapor may be present and tolerable in the system. It is 5 also desirable, as is well known, that the quality be substantially equal to one so that liquid refrigerant in a quantity that is sufficient to damage the compressor 10 during the compression process is not present.

In conventional systems of this sort, it has been typical to place the accumulator 46 upstream of the second flow path 28 of the 10 suction line heat exchanger 26 and downstream of the evaporator outlet 40. In such a conventional configuration, saturated refrigerant vapor enters the suction line heat exchanger 26 which then is superheated as a result of the heat exchange with the high pressure refrigerant stream exiting the gas cooler 16. Superheated refrigerant vapor has a lesser density than saturated vapor and consequently reduces the efficiency of the compressor. 15 Thus system efficiency is increased by locating the accumulator 40 between the compressor inlet 14 and the second flow path 28 of the suction line heat exchanger 26 as in this embodiment of the invention.

A further efficiency occurs through use of the invention in the 20 configuration illustrated in Fig. 1. With the suction line heat exchanger 26 located between the evaporator outlet 40 and the accumulator 46, the fact that two phase refrigerant, i.e., refrigerant having a quality less than one, is present in heat exchange relation with high pressure refrigerant received 25 from the gas cooler 16, there is a greater reduction in the temperature of the compressed refrigerant as it exits the first flow path 24 because of a

5 greater temperature drop along the first flow path 24. This reduction has the effect of reducing the quality of the refrigerant entering the evaporator 38 which in turn has the effect of reducing possible flow maldistribution within the evaporator for greater efficiency. This in turn has the effect of
improving evaporator capacity because the evaporator is used more effectively with fewer regions seeing superheated vapor as well as improving air side temperature distribution of air driven by the fan 40 through the evaporator 38.

10 Furthermore, because the second flow path 28 receives two phase refrigerant, and refrigerant flow therein is two phase along at least part of its length, the second flow path 28 operates isothermally over much of its length. This means that the suction line heat exchanger is more effective since it does not materially contribute to refrigerant superheat entering the compressor 10 and has the beneficial effect of lowering the
15 quality of the refrigerant entering the evaporator to provide improved evaporator capacity.

20 Turning now to Fig. 2, a highly preferred embodiment of the invention that provides a greater degree of control and regulation is described. Where like components are employed, like reference numerals are given.

25 In the embodiment illustrated in Fig. 2, the accumulator 46 is located between the evaporator outlet 40 and the second flow path 28 of the suction line heat exchanger 26. The suction line heat exchanger 26, and specifically, the second flow path 28 thereof, discharges into the inlet
14 of the compressor.

In this embodiment, refrigerant at a quality of less than 1 is placed in a conduit 50 that interconnects the outlet side of the accumulator 46 and the inlet side of the second flow path 28. Within the suction line heat exchanger's second flow path 28, any liquid phase refrigerant is evaporated so that refrigerant at a quality substantially equal to 1 or as a super heated vapor is flowed through a conduit 52 to the inlet 14 of the compressor 10. The embodiment of Fig. 2 is particularly useful in vehicular air conditioning systems. Such systems are typically optimized with the vehicle engine at idle speed. At idle speed, the mass flow rate of refrigerant through the vehicular air conditioning system is at a minimum and it is desired that it be sufficient so as to provide adequate cooling. At higher engine speeds, the mass flow rate of refrigerant is increased as compressor speed is increased and attaining the desired cooling is not a problem. Consequently, it is at an idle condition where greatest efficiency is required, i.e., it is at idle conditions where refrigerant in two phases, i.e., at a quality less than 1, is most required in the second flow path 28 of the suction line heat exchanger 26.

In order to assure that refrigerant at the desired quality less than 1 is placed in the conduit 50, the invention proposes certain modifications to the accumulator 46.

Fig. 3 shows one such modification.

In the usual case, the accumulator 46 includes a housing 60. Lines 62 and 64 within the housing, which in actual practice are imaginary, respectively designate the intended level of liquid refrigerant and the intended level of lubricant within the housing 60. A U or J-shaped tube 66

is located within the housing 60 and includes a first leg 68 having an open end 70 which is located above the intended level of liquid refrigerant 62. The tube 66 includes a second leg 72 which is connected to the first leg 68 by a bight 74. It will be noted that bight 74 is located below the intended level of lubricant 64 within the housing 60. The housing also includes an inlet (not shown).

The upper end of the leg 72 extends out of the housing 70 and is connected to a conduit 76 which extends to a tee 78. The tee 78 is connected the line 50 and extends to the second flow path 28 of the suction line heat exchanger 26 (Fig. 2).

The accumulator housing 60 also includes an outlet 80 that is located below the intended level of liquid refrigerant 62 and above the intended level of lubricant 64. The outlet 80 is also connected to the tee 50.

Finally, a fluid flow restriction 84, such as a valve, is located in the conduit 76 as illustrated in Fig. 3.

In operation, refrigerant is discharged into the accumulator 48 and to the extent it is in two phases, it will separate into vapor which will occupy a vapor space 86 above the intended level of liquid refrigerant 62 and liquid refrigerant which will occupy the volume between the two lines 62 and 64. Lubricant, conventionally carried by the refrigerant for purposes of lubricating the compressor 10 (Figs. 1 and 2), settles to the bottom of the housing.

The bight 74 includes a small opening 88 below the intended level of lubricant 64.

In any event, refrigerant vapor will enter the tube 66 through the open end 70 and pass downwardly past the port 88 where it will entrain or educt lubricant from the housing 70 in the flowing refrigerant vapor stream to be carried to the compressor 10 to lubricate the same. At the 5 same time, liquid refrigerant will be urged out of the outlet 80 to the tee 78 where it will mix with the refrigerant vapor and entrained lubricant which exits the upper end of the leg 72. The restriction 84 provides a desired regulation of the ratio of refrigerant vapor flow to liquid refrigerant flow to achieve the desired quality of refrigerant to be directed to the second flow 10 path 28 of the suction line heat exchanger 26.

Fig. 4 shows a modified embodiment of an accumulator. Where identical components are employed, they are given the same reference numerals and will not necessarily be redescribed in the interest of brevity. In this embodiment, the outlet 80 is omitted in favor of one or 15 more ports in the leg 72. The ports are given the reference numeral 92 and as can be appreciated from Fig. 4, are located below the intended level of liquid refrigerant 62 and above the intended level of lubricant 64. The ports 92 are simply small holes, much like the port 88 for the lubricant. As a consequence, when refrigerant vapor from the space 86 enters the open 20 end 70 of the tube 66 and passes therethrough to the conduit 50, lubricant is entrained or educted at the port 88 and liquid phase refrigerant is educted or entrained into the vapor stream at the ports 92. Consequently, a stream emerges from the accumulator shown in Fig. 4 to the conduit 50 that has a quality less than 1.

The particular quality desired can be controlled by appropriate sizing of the ports 92 as well as by selection of the number of the ports 92.

5 The embodiment of Fig. 4 has the advantage over that shown in Fig. 3 in that the flow restriction 84 can be omitted along with the outlet 80 and the tee 78 to accomplish the same results with a relatively minor addition to a conventional accumulator. The ports 92 can be simple holes or may be angled in the direction of refrigerant flow to provide a venturi-like action.

10 Most interestingly, modern day accumulators in refrigeration systems are conventionally designed to prevent any liquid refrigerant from exiting the accumulator in order to protect the compressor from damage. In the embodiments illustrated in Figs. 2, 3 and 4, the desired operation is just the opposite, namely, that the accumulator is designed to intentionally cause liquid refrigerant to leave the accumulator to be directed to the second flow path 28 of the suction line heat exchanger as a result of being educted by or entrained in the exiting flow of saturated refrigerant vapor to the suction line heat exchanger 26. The embodiments shown in Figs. 3 and 4 provide simple and inexpensive means of accomplishing this function 15 with the embodiment of Fig. 4 providing even greater simplicity than that of Fig. 3.

20 As a consequence of the invention, in any of its embodiments, two phase refrigerant, that is, a refrigerant having a quality of less than 1, is directed to the second flow path 28 or low pressure side of the suction line heat exchanger 26 to improve the efficiency of operation of the same 25

by lowering the quality of the compressed refrigerant on the high pressure side that is flowing to the evaporator 38. Furthermore, because there is isothermal operation within the second flow path 28 over much of its length, refrigerant applied to the compressor inlet 14 is at a considerably 5 lower temperature than in conventional systems. This provides advantages in terms of reducing the thermal load on the compressor 10 and is highly desirable in that thermal degradation of the lubricant typically contained in such systems is minimized or virtually eliminated altogether. Thus, not only is efficiency of operation of the entire system enhanced, but system longevity is increased as well. 10